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Performance of the charge injectors of the ALICE Silicon Drift Detectors

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Abstract

The Inner Tracking System (ITS) of the ALICE experiment at the LHC uses high precision Silicon Drift Detectors (SDD) in two out of the six cylindrical layers. In these detectors, the drift speed is significantly influenced by temperature variations. The drift velocity is determined by measuring the drift time of electrons injected at fixed known locations in the sensor volume by means of dedicated MOS devices (injectors). We report the results of a study aimed at characterizing the time needed to stabilize the detector temperature and to have the injectors working with full efficiency. The study was carried out in 2010 and is based on the analysis of a series of dedicated calibration runs, which were taken every few minutes for a period of two days after powering on the detector.

Keywords: semiconductor detector, silicon drift detector, MOS charge injector

1. Introduction

The Inner Tracking System (ITS) of the ALICE experiment [1] at the LHC is composed of six cylindrical layers of silicon detectors. High precision Silicon Drift Detectors (SDD) equip the two intermediate layers located at radial distances of ~15 cm and ~24 cm from the beam axis .

In a SDD, under the effect of an applied electric field, the electrons, generated by the crossing particle, drift along a direction parallel to the surface of the wafer towards an array of anodes located at the sensor edges. The coordinate along the drift direction ($r\varphi$) is determined by the measurement of the drift time, while the centroid of the charge collected by the anodes gives the second coordinate (z).

The ALICE SDD were produced by Canberra Semiconductors on 300 μm thick 5” thick NTD wafers with a resistivity of 3 kΩ·cm. Their active area is 7.017×7.526 cm^2 and it is split into two drift regions, where electrons move in opposite directions, by a central cathode kept to a nominal voltage of -1800 V. A second bias supply of -40 V keeps the biasing of the collecting region independent of the drift voltage. Each drift region is equipped with 256 collecting anodes (294 μm pitch).

The SDD modules are mounted on linear structures called ladders: on the inner layer (at r≈ 15 cm) there are 14 ladders with 6 modules each, while on the outer layer (at r≈ 24 cm) there are 22 ladders with

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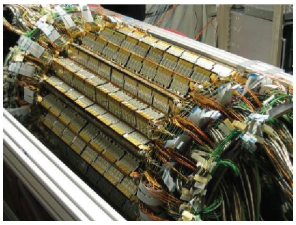

Fig. 1. Picture of the Silicon Drift Detectors, barrel with the electronics.

8 modules, for a total of 260 modules. Ladders and modules are assembled in such a way to ensure full azimuthal coverage (Fig.1) over the pseudo-rapidity range $|\eta| < 0.9$ [2].

The SDD is required to provide a spatial precision of about 35 μm along the drift direction and 25 μm along the anode axis. The maximum drift path is 35 mm .

The drift speed is significantly influenced by temperature variations : ($v \propto T^{-2.4}$), giving a 0.8%/K variation at room temperature. It is about 6.5 μm/ns at the bias voltage of -1.8 kV and at the normal operation temperature ($20 - 25^{o}$C) [3].

To achieve the required resolution on the drift coordinate, it is necessary to assure a temperature stability of 0.1 K, or, alternatively, to implement a precise monitoring for the drift velocity during operation.

A cooling system has been designed to provide a temperature stability of 0.1 K. [4] The cooling system has 52 underpressure demineralized-water circuits. A dedicated interlock system constantly monitors pressure and flow, thus guaranteeing leak-safety and adequate heat removal.

The measurement of the drift velocity is performed for each drift region by means of three rows of point-like MOS charge injectors. The details on the injector design are given in the next section.

2. Drift speed calibration strategy

The drift velocity calibration is determined by measuring the drift time of electrons injected in the sensor volume at fixed known locations of the sensor volume by means of dedicated MOS devices (injectors), whose operating principle is shown in Fig.2. The idea is to exploit the electrons which are accumulated in the potential pocket below the oxide by the positive charge of the oxide itself [5]. A p^{+} implant runs below the oxide in order to prevent the formation of the electron accumulation layer; this is allowed only in certain areas where the p+ implant is interrupted. These rectangular areas constitute the actual injectors. By applying a negative pulse to the metal gate, the electrons can overcome the potential saddle point and be injected in the silicon bulk. The metal gate is 100 μm long (along the anode coordinate) and 20 μm wide (along the drift coordinate).

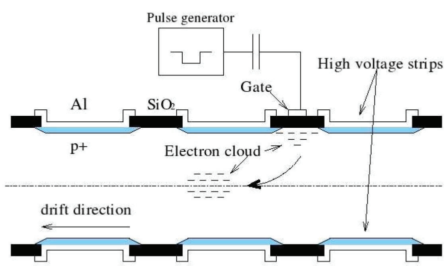

Fig. 2. Principle of operation of the MOS charge injetors

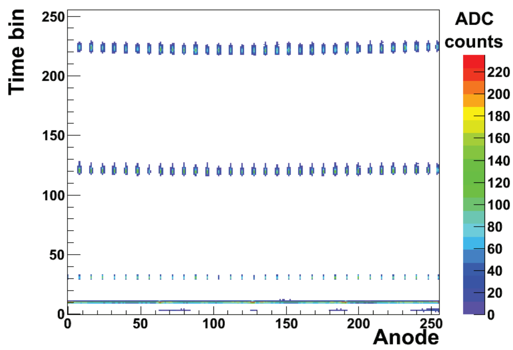

Fig. 3. Display of an injector event for one drift region of a module with working injectors: the three MOS injector lines are clearly visible.

The possibility of measuring frequently the drift velocity in different points of the sensitive area is an item of paramount importance when working with SDD to avoid biases due to temperature variations [6, 7]. It is expected that the actual drift velocity is not constant along the anode coordinate because the temperature is higher at both detector edges due to the heat dissipated by the voltage divider. For this reason, it is important to measure the drift velocity as a function of the anode coordinate. So, for each SDD module, 99 injection points are implemented in each drift region. The injectors are distributed along 3 lines located at different distances (3.225; 17.625; 34.425 mm) from the collection anodes, thus allowing one to measure the drift speed in 33 positions along the anode axis (about 1 every 8 anodes).

To extract the relevant parameters for data reconstruction calibration runs are performed during the ramp-up phase of each LHC fill. In particular, the drift speed is measured with the injector runs, which are special SDD calibration runs where the MOS injectors are activated in order to inject charges in known positions. An injector run collects 50 events in about one minute of data taking. Baseline equalization and zero suppression [3] are activated. The result of the injector data analysis is the computation of the drift speed as a function of the anode number for each SDD drift region. The display of one injector event for one drift region is shown in Figure 3. An example of drift speed values as a function of the anode number of one drift region is reported in Figure 4. The drift speed was very stable over the period of the 2010 PbPb data taking, as it can be seen in Fig.5 for two typical SDD modules. The different value of drift velocity

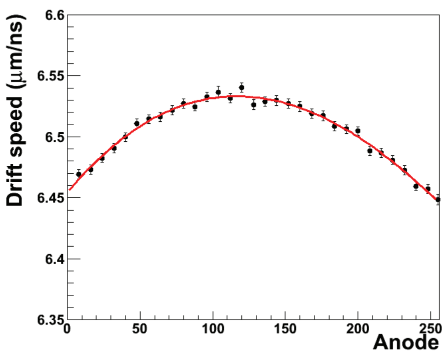

Fig. 4. Measured drift speed as a function of the anode number on one drift region. The drift speed is extracted by fitting the measured time as a function of the known drift distance for the three corresponding injectors.

exhibited by the two modules shown in Fig.5 reflects the different temperature of the SDD layers in which the modules are located.

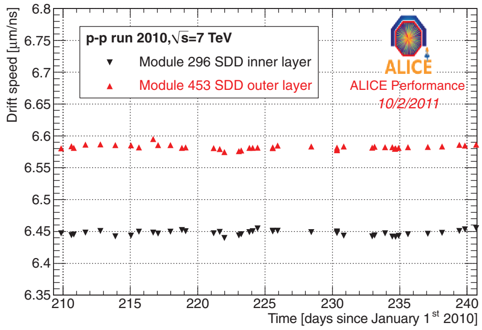

Fig. 5. Drift speed in two selected SDD modules as a function of time during Pb-Pb 2010 data taking.

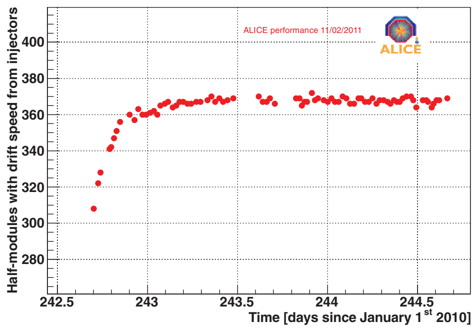

Fig. 6. Number of SDD half-modules (drift regions) with working injectors vs. time in a period of 2 days after the switch on of detector HV.

3. Results from injector performance studies

The SDD are occasionally turned off for maintenance interventions during the LHC technical stops. These periods in which the high voltages are turned off affect both the detector operation temperature and the injector performance. In the construction phase and laboratory tests it was observed that on some modules, after powering on the high voltage, a long time period (hours) was needed for the injectors to reach full efficiency. It was already observed that this recovery time is shorter if the period with HV off was short (less than 1 hour). Because of this concern, it is very important to determine how long it takes to resume the nominal detector operational conditions after the detector is turned on again. This will define the minimum time to wait before the detector can be considered ready for new physics measurements.

Therefore, special studies were carried out after each technical stop in 2010 by collecting injector runs every 20 minutes for 2 days after re-powering the detector. This allowed us to study the time needed by each individual detector module to reach the required temperature stability and by the injectors to work with full efficiency. Here we report the results from the study performed on one particular technical stop where the SDD were kept off for 8h15min.

Fig.6 illustrates the time needed for recovering the injector efficiency after repowering the detector. The fraction of the half-modules with working injectors reaches 368, that is the maximum number of drift

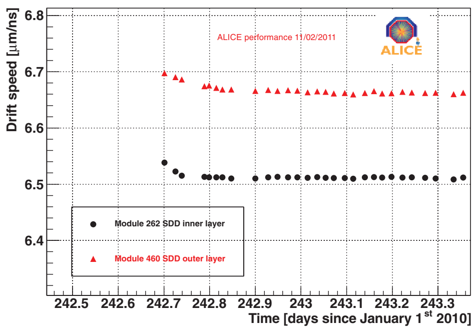

Fig. 7. Drift speed vs. time for 2 SDD modules during a period of 2 days after the switch on of detector HV.

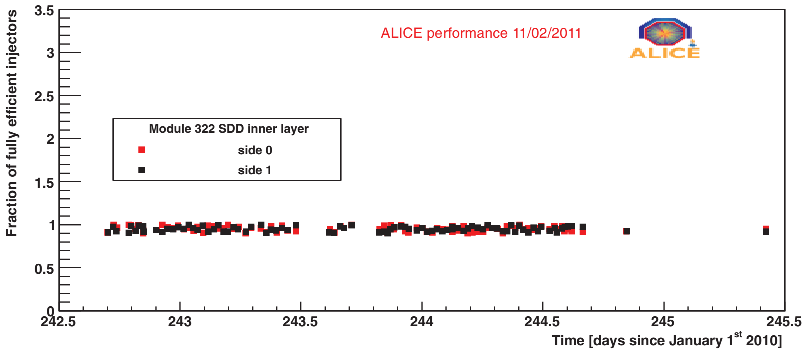

Fig. 8. Fraction of working injectors in a typical SDD module vs time.

regions (out of the total of 520) where the drift speed can be measured by using the injector information. More details are in Table 1. About 32 hours were needed to have the injector reach full efficiency for all modules.

Fig.7 shows the drift velocity as a function of time for two selected SDD modules during the ~28h-long period after powering on the SDD in which the dedicated injector runs were carried out. The time needed for temperature stabilization is about 2.5 hours. After this time the drift speed is proven to be stable during the whole data taking period (see the example in Fig.5) . Finally, the stability of the number of working injectors was checked module-by-module during the 48-hours subsequent to the SDD powering on.

Fig.8 shows an example of the module that has most of the injectors working on both drift sides. The results obtained for the different studies reported in this section confirm that the injector performance of 97% of the modules is in agreement with the design specifications after a period of about 24 hours from the SDD powering on. The MOS injectors therefore provide an efficient tool to monitor the stability of the detector temperature during the data taking.

4. Summary

To reach the nominal resolution along the drift coordinate it is necessary to measure frequently the drift speed with MOS charge injectors. Therefore it is important that the injectors work with high efficiency in order to perform the optimal calibration of the drift velocity for each detector module. Between consecutive calibration injector runs, the temperature has to be kept stable within 0.1 K in order to guarantee the required resolution on the drift speed coordinate.

Table 1. Summary of the time needed to recover full injector performance on the SDD modules. Percentages, are normalized to the number of modules with working injectors.

Recovering after HV switch on	Number of the modules(%)
immediately	55
within first 6 hours	19
from 6 to 12 hours	15
from 12 to 24 hours	8
more that 1 day is needed	3

Moreover, it is very important to determine how long it takes to resume the nominal conditions after repowering the detector after a long period of time in which it was kept off. Frequent calibration runs were performed to obtain a detailed characterization of the injectors behaviour immediately after powering the detector and during stable running conditions.

The results demonstrate good operating stability for continual investigation during 48 hours after powering on the SDD. The studies of the recovery time show that for 55% of the modules the recovery is immediate after HV switch on and the injectors of 97% of the modules start working within 1 day, while only for 3% of the modules the recovery takes more than 1 day.

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